# Soft-landing and hazard avoidance aspects for future exploration missions

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IPPW5 - Session 2 – June, 25th

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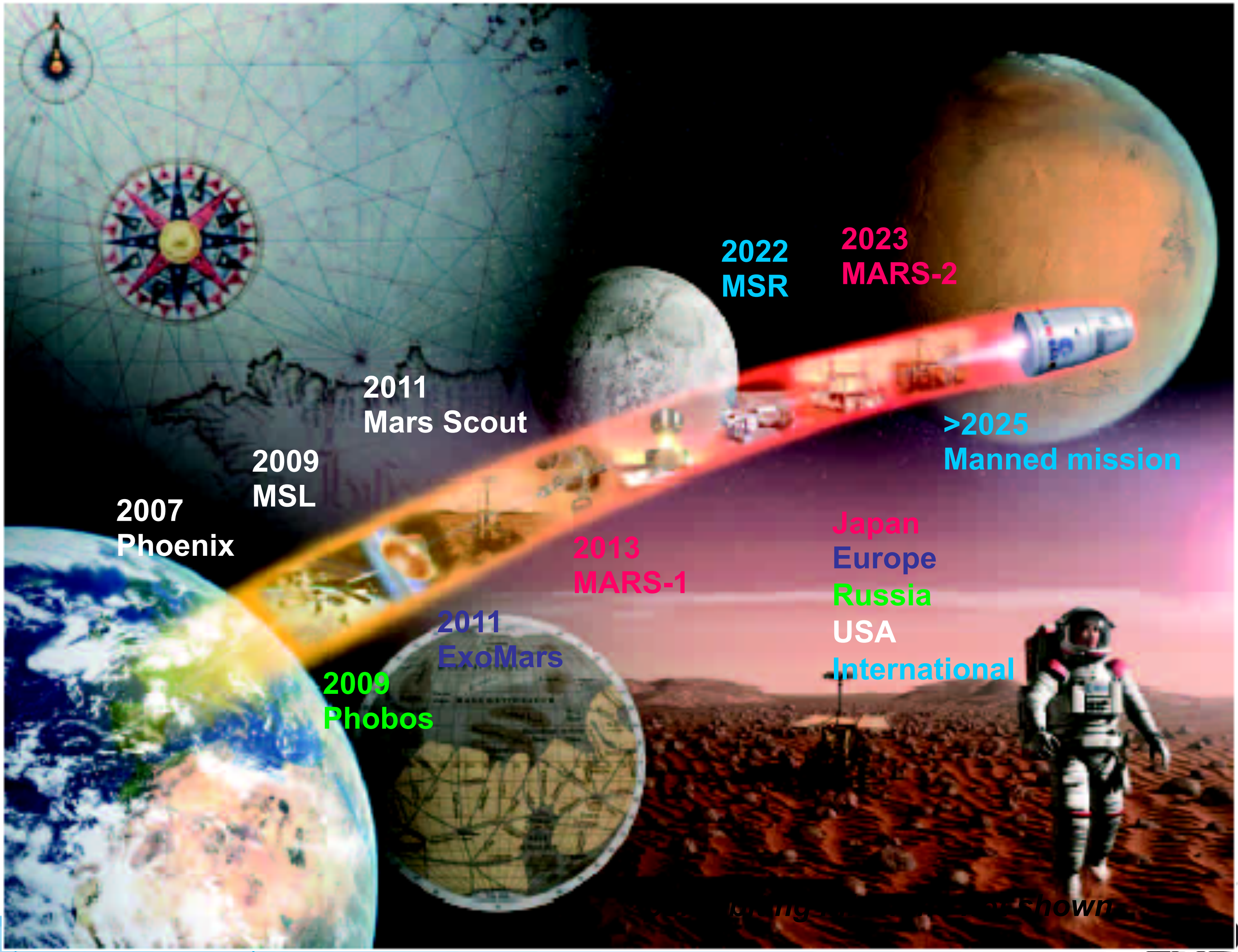


# The way to pave the Martian exploration (2/2)

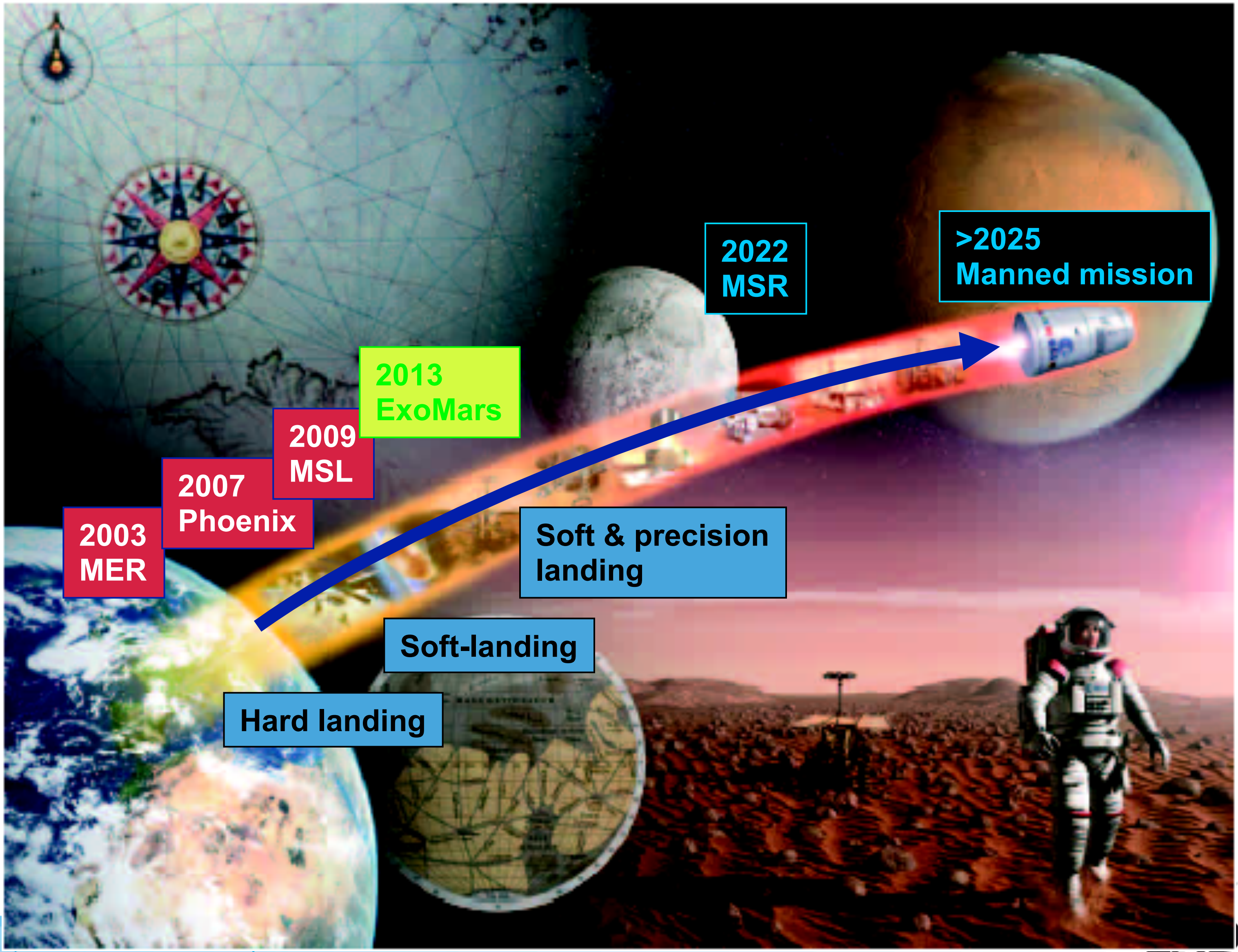
- Near term perspective 10 - 15 years
  - Soil analysis: Phoenix
  - Soil analysis & rover: ExoMars, MSL, MARS-1
  - Mars sample return: Phobos-Grunt
- Longer term:
  - Mars Sample Return: MSR international cooperation (NASA +ESA), MARS-2
  - Manned mission on an international cooperation

**MASTER AND IMPROVE the**
**ENTRY, DESCENT and LANDING (EDLS) technology**
**towards the future**

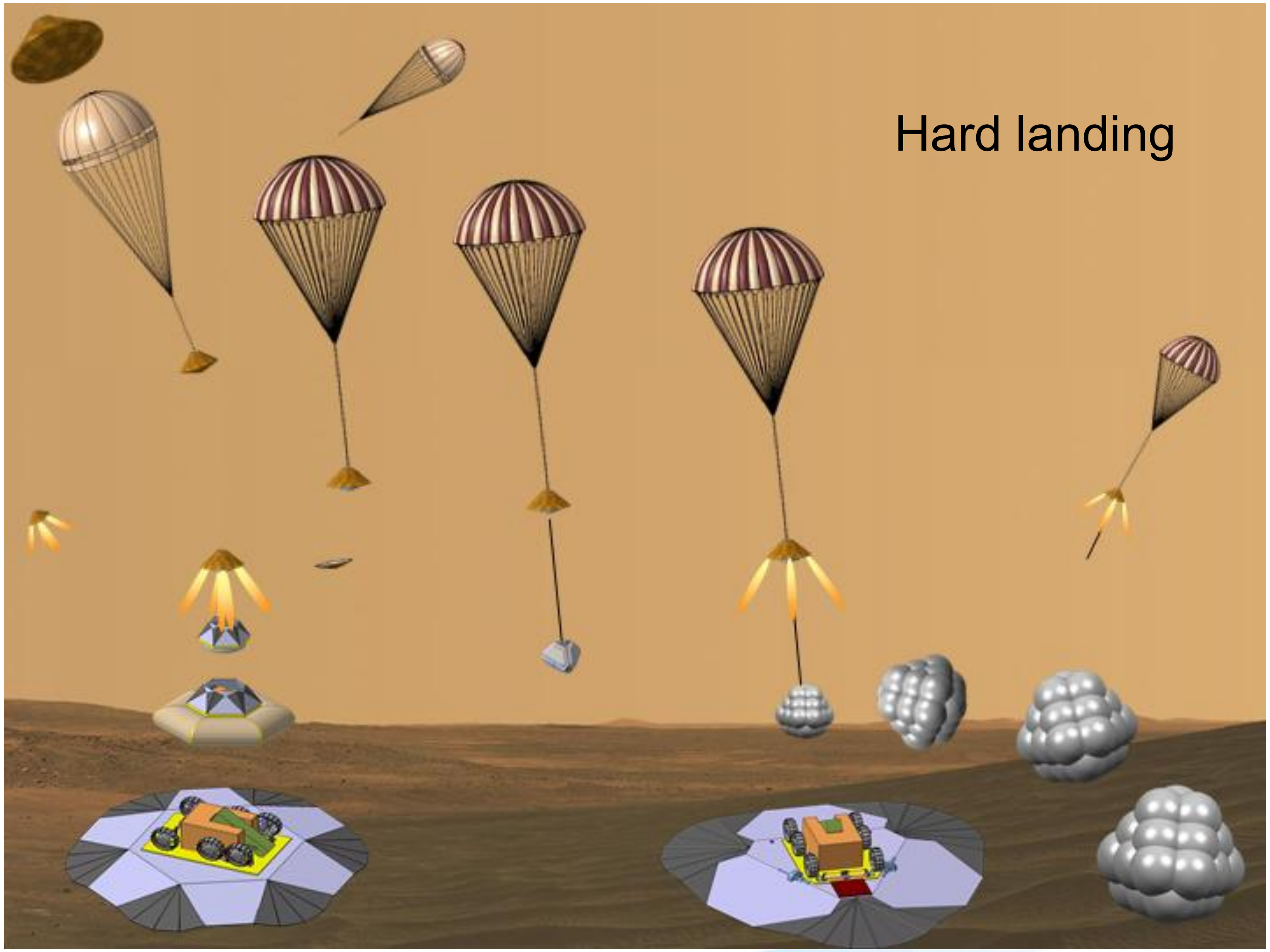
# EDLS – definition & main goal

- main objective: guarantee the EDL phases, bring to the Martian surface the scientific payloads safely and keep their integrity all along the mission
- Key factor success:
  - Mastery of the ballistic coefficient $\beta$,
  - Management of COG & Motion around the COG
- EDLS= choice and optimisation of design and parameters for the whole sequence until touchdown

# EDLS – the new missions

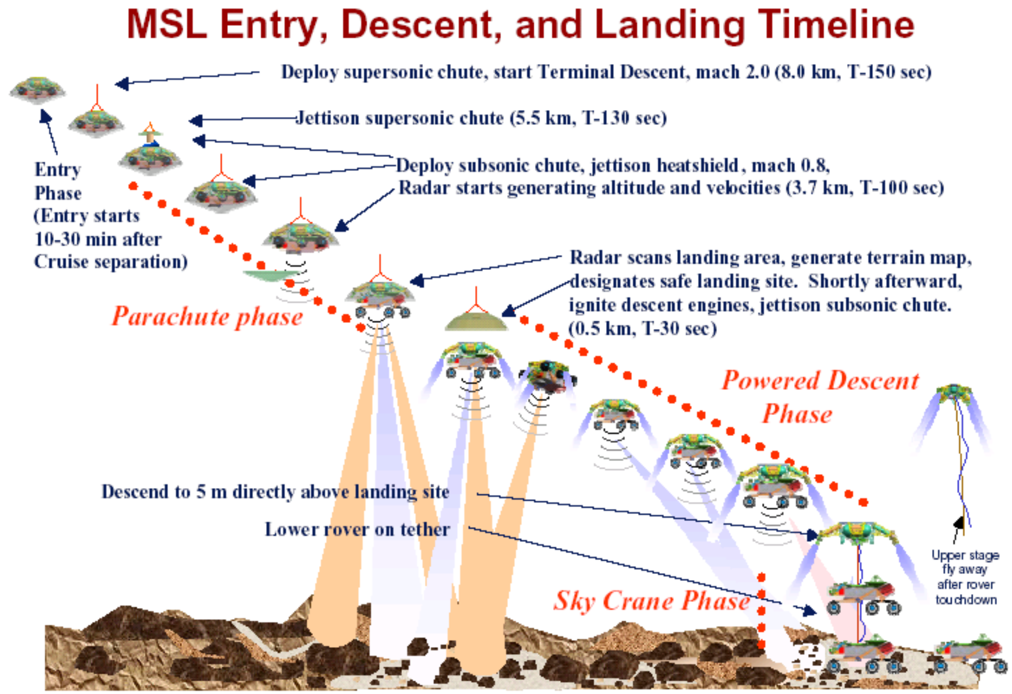


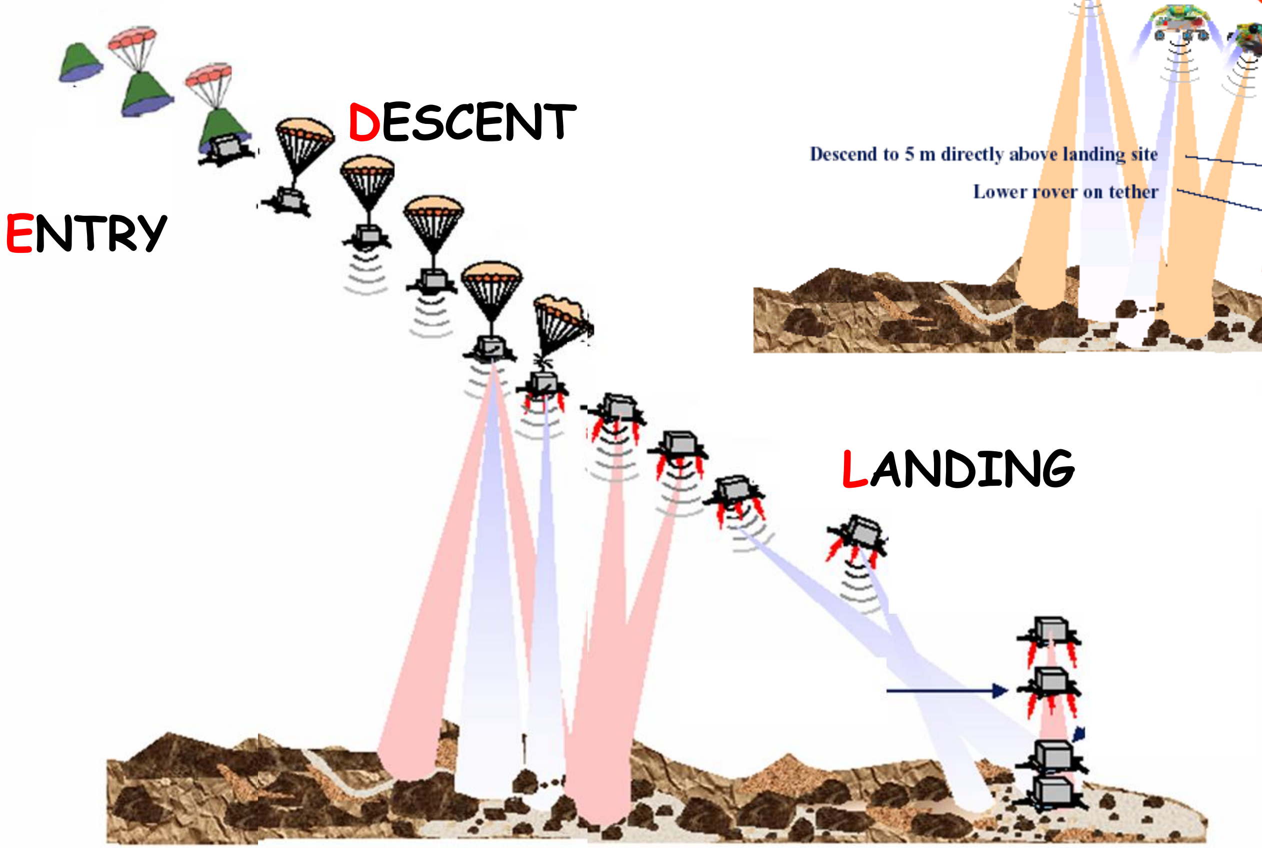
# EDL sequence with airbags (1/2)



# EDL sequence with legs (2/2)

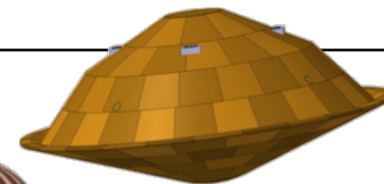
Soft and precision landing

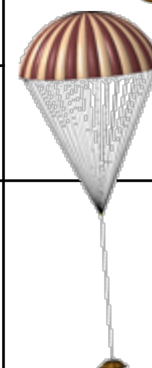


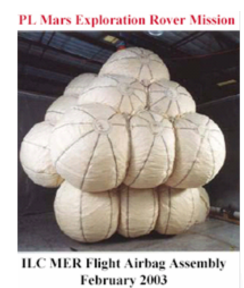



# EDLS – technologies required

| Mission phase | EDLS main functions per phase | Foreseen concept/device | Sketches |
|---|---|---|---|
| Separation and Exo-atmospheric phase | Ensures a ~ null angle of attack at entry | Axis-symmetrical shape | |
| Entry phase | Decelerate and stabilise the DM | Heat shield and back-cover | |
| Descent phase | | Parachutes<br><br>Propulsion ignition and activation | |
| Landing phase | Land on Mars<br>Minimise the shock at landing and detect that the probe is motionless | Vented Airbags, Unvented airbags or landing gears | |



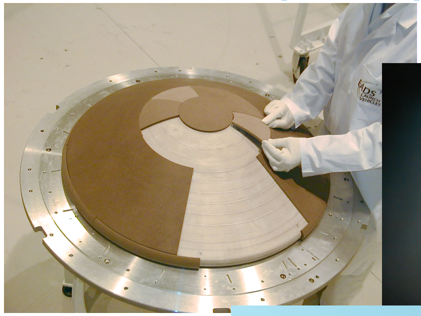




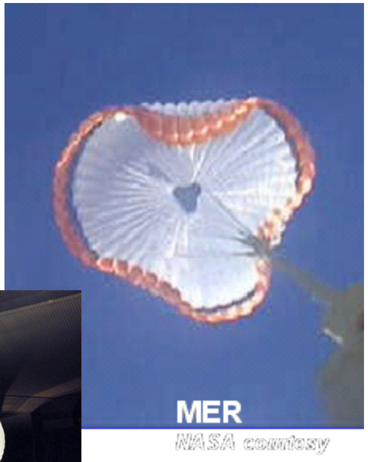


# EDLS technology constraints (1/2)

- Aeroshell
  - Structure: mastered
  - TPS: ablative material needed
  - Norcoat Liège baseline
  - Density: 0.47
    - Thickness: from 1.5 to 150 mm
    - Qualified in $CO_2$ for Martian entries
    - Heat fluxes up to 2 MW/m2



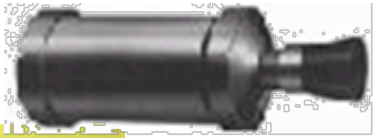
- Parachutes & mortar: mastered in Europe
  - Type: Viking tests, Beagle 2 tests
  - Materials: MER, MPF, HUYGENS
  - Mortar: MER, HUYGENS




# EDLS technology constraints (2/2)

- Propulsion: solid and liquid mastered in Europe
  - Off-the-shelf equipment
  - Delta qualification necessary to adapt for the mission
- Vented airbags:
  - Proven in Earth environment,
  - Not qualified in Martian one,
- Unvented airbags:
  - flight-proven on Mars by US,
  - not proven by Europe
  - Constructional principals known, specific laboratory tests  needed for key properties
- Landing legs
  - Low-risk technology based on crushable materials and deployment systems

MER TIR



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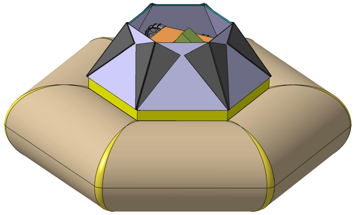
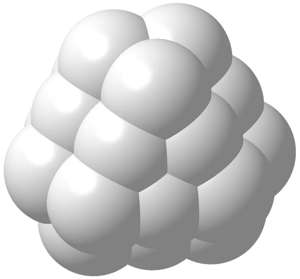
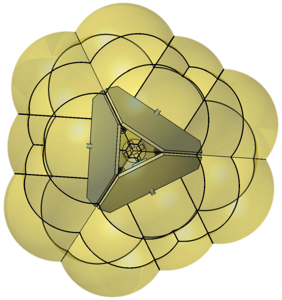






# EDLS – the different options

| | parameters | entry | descent | landing | examples |
|---|---|---|---|---|---|
| Simple hard landing | $M \leq 100$ kg<br>V ~20 m/s<br>P ± 100 km | Ballistic blunt shape with 70° cone angle | 2-stage chutes | airbags | Beagle 2, NetLander phase B |
| hard landing | $M \leq 1000$ kg<br>V ~20 m/s<br>P ± 60 km | | 2-stage chutes<br><br>Solid retrorockets | airbags | Mars Pathfinder<br>MER |
| Soft-landing | $M \leq 2000$ kg<br>V < 5 m/s<br>P ± 30 km | | 2-stage chutes<br><br>Attitude control system | Airbags or landing gears | Phoenix, Viking both with landing gears |
| Soft & precision landing | $M \leq 2000$ kg<br>V < 5 m/s<br>P ± 5 to 10 km | guided blunt shape with 70° cone angle | | crane | MSL |

# EDLS – what is affordable for Europe?

- Contribute to the way to Mars thanks to a EDLS with growth potential (future missions) and explore new areas
- Come to a versatile EDLS for bigger entry vehicles
- Build on experience gained in Europe for TPS, chutes and propulsion
- Reduce the risks on technologies not mastered in Europe

➔ **Soft-landing will become mandatory**

➔ **With precision landing**

➔ **With hazard avoidance**

# Soft-Landing/hazard avoidance: mastery of additional Key Technologies

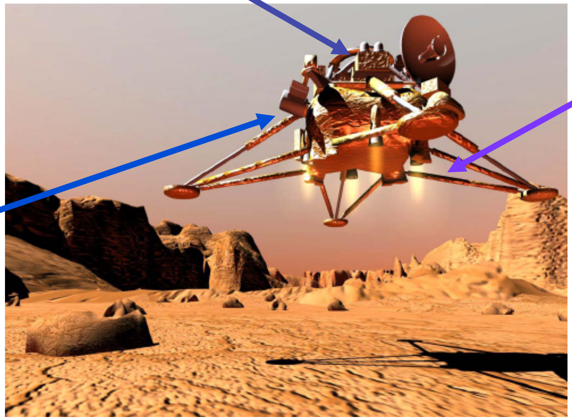
**Navigation & Flight Control System**

Real-time control loop which could deal with:
- **control of the trajectory & attitude**
- **landing site environment analysis**
- **recomputation of the new landing target**

**Sensors devices**

- **Navigation sensors**
- **Landing area analysis sensors allowing ground hazard detection**

**in a timeline compatible with the trajectory control & robust to the operating environment**

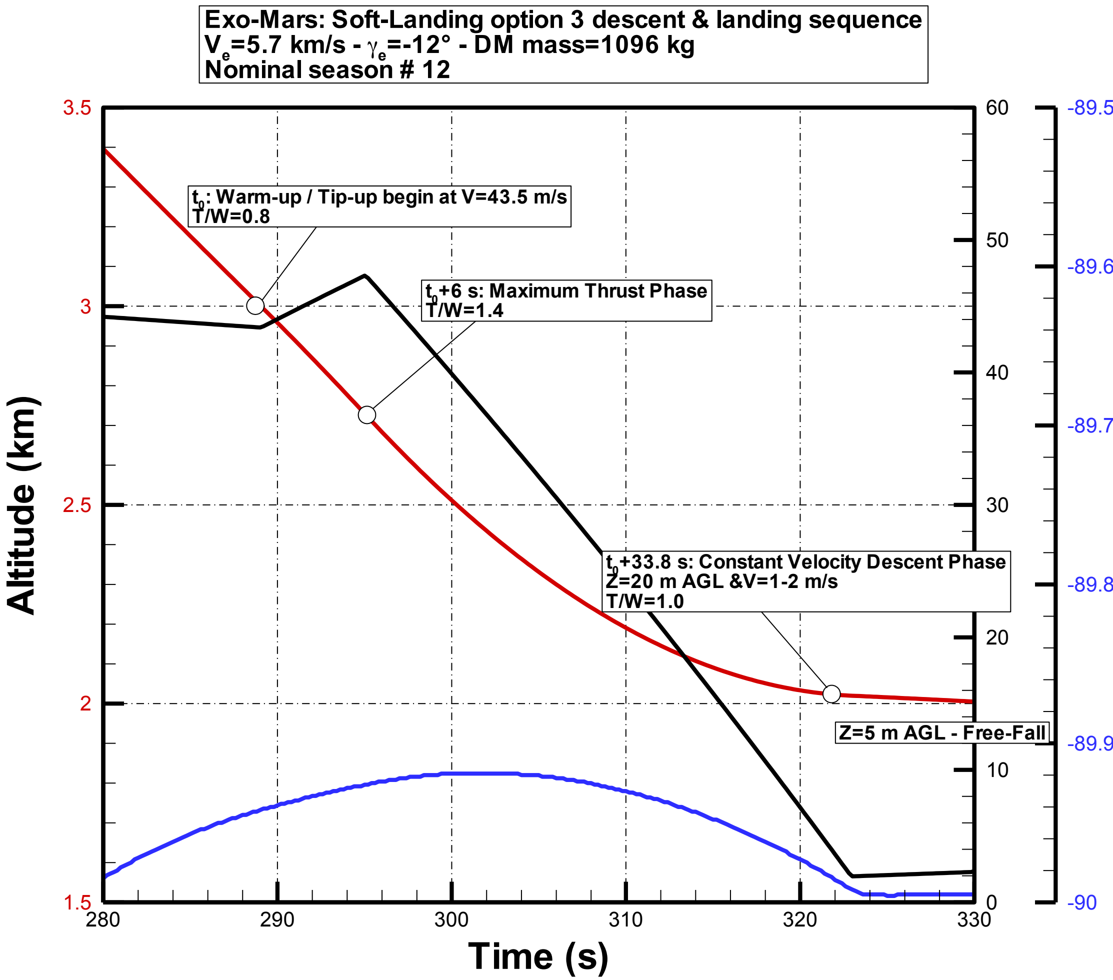


**Propulsion devices**

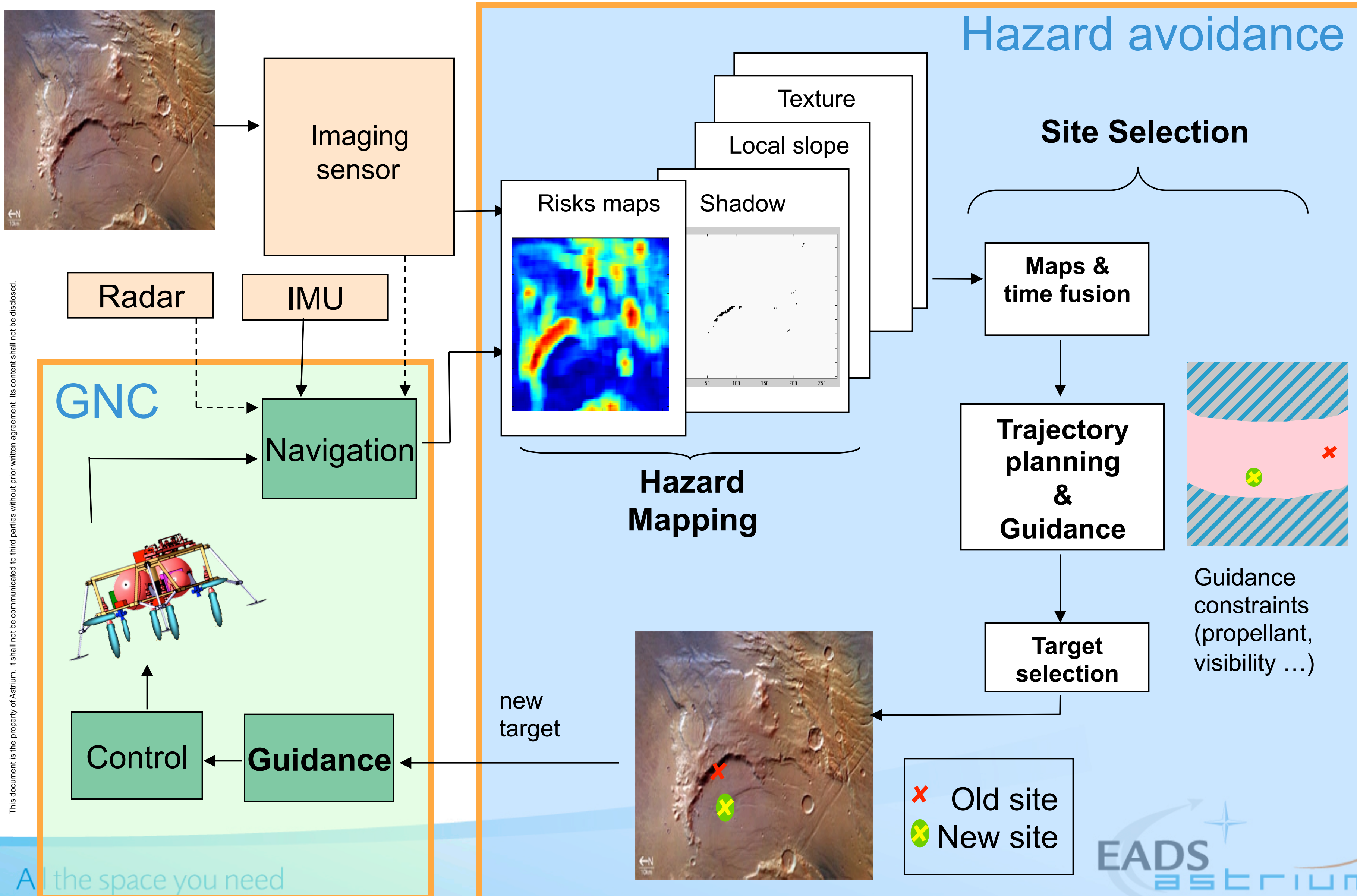
**A trajectory control device,** reactive and performant enough to fit with :
- **Braking during descent**
- **Controlling attitude of vehicle**
- **Providing the fine manoeuvrability required for hazard avoidance during final approach**

# Typical final landing with soft-landing

- **Powered descent propulsion law:**
  - Initial altitude = 1000 m AGL
  - Warm-up / Tip-up duration: 6 s / T/W=0.8
  - Braking Phase (Gravity Turn or MBTL) T/W = 1.4
  - CVD phase @ Z=20 m down to 5 m AGL where T/W=1.0
  - Escape Phase
- **Propulsion System based on SCA Ariane 5:**
  - 12 SCA AR5 engines canted by 20° (400 N with possibly 450 N maximum thrust each – see ARD) used for braking & control



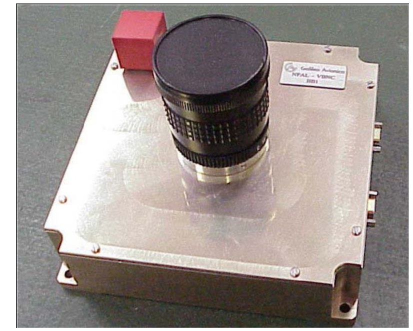
# Hazard avoidance architecture

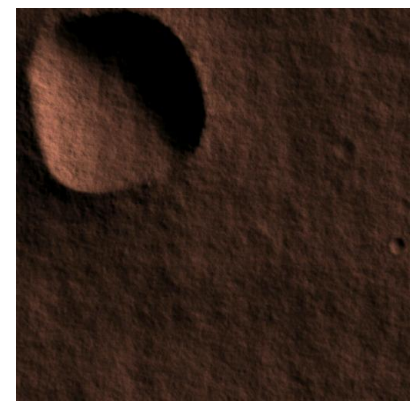


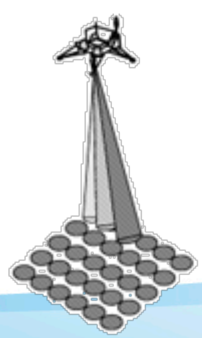
# Imaging sensor

| | Advantages | Drawbacks |
|---|---|---|
| **Camera** | ▪Low weight, volume and power<br>▪Flight proven (MER) | ▪Sensitive to environment and blur<br>▪Estimation of slope difficult |
| **Lidar** | ▪Direct access to 3D data<br>▪Hazard mapping Simple algorithm | ▪High weight, volume and power |

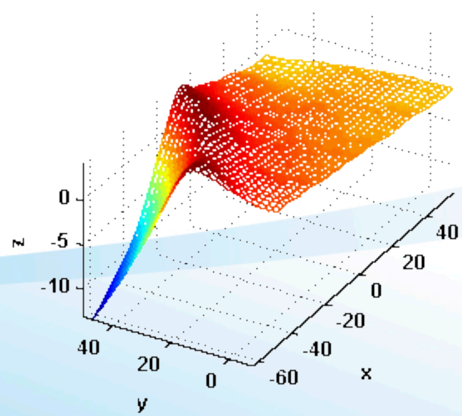
NPAL Camera







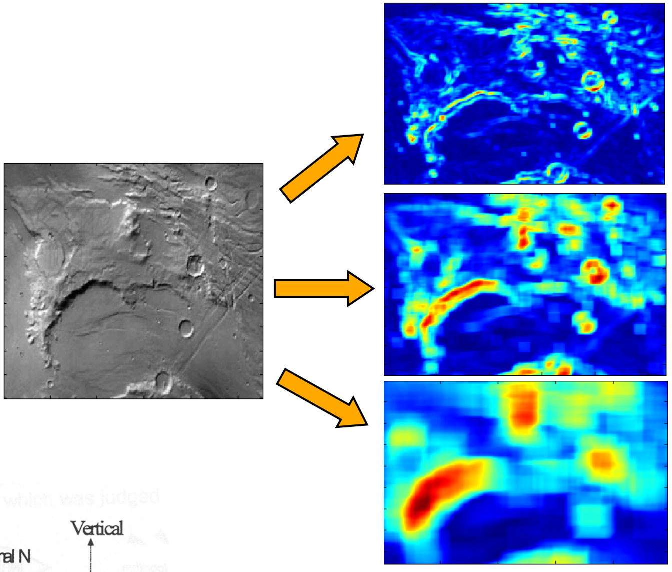
Scanning Beam

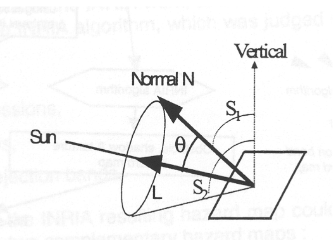


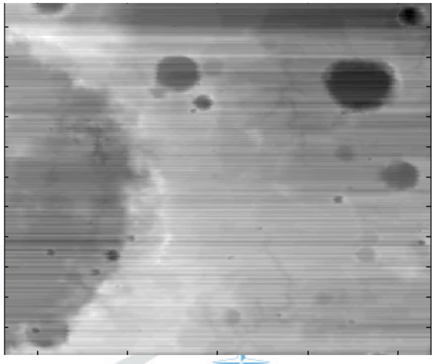
# Vision based Hazard mapping (1/2)

- Detection of shadows
  - simple thresholding
- Detection of rocks, craters rims, edges, etc
  - Image texture analysis
  - Correlation or (multiscale) variance
- Estimation of local slope
  - Shape from shading methods
    - Strong hypotheses
    - Minimum slope computation
    - Carlotto line integration method

  ➔Poor performances in general
  - Improvement possible by using feature points tracked by navigation





# Vision based Hazard mapping (2/2)

- In-house development: structure from motion

Image1

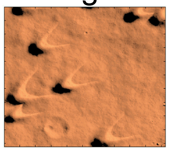
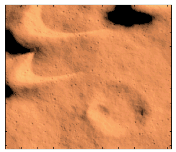
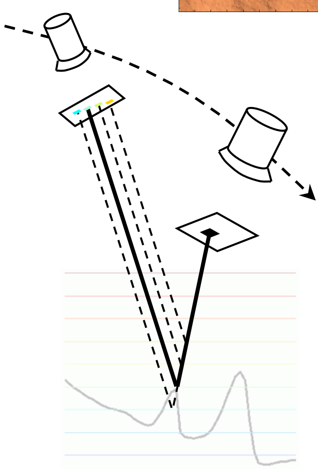


Image2





Stereo principle:

zone choice in image2
+
altitude assumption on corresponding terrain

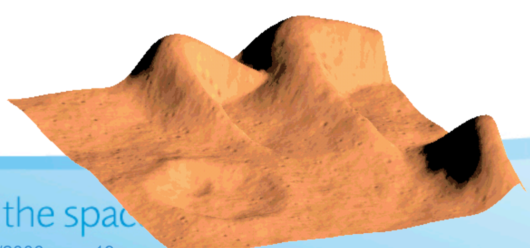
↓

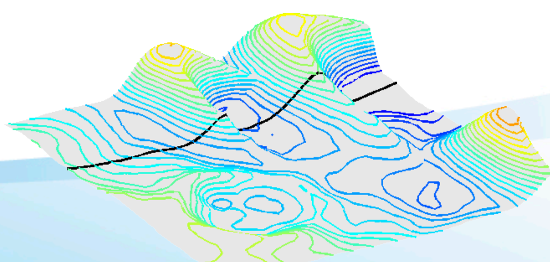
warping into image1

↓

Match if assumption verified

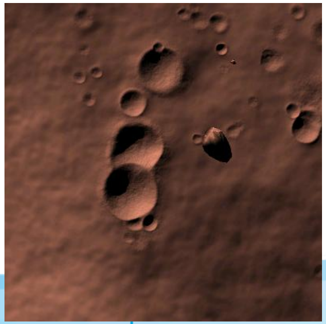
- Low sensitivity to atmosphere
- Need for non uniform terrain for efficient correlation
- Performances function of navigation accuracy



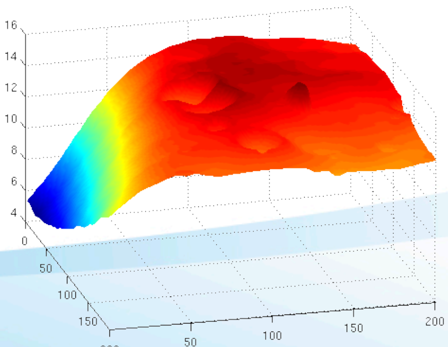


# Lidar based Hazard mapping

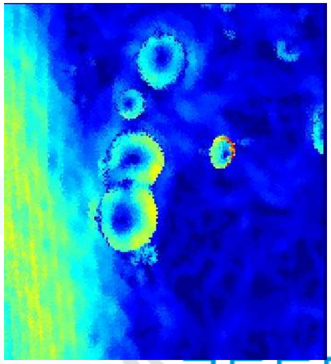
- Lidar gives direct access to 3D data
- Data samples need to be corrected for movement during the scan and projected onto regular grid ➔ 3D map of terrain
- Slope information obtained from Least Square or Least Median square Plane fitting
- Roughness (rock size) obtained from difference between plane and measured surface



Terrain




DEM from LiDAR



Slope Map

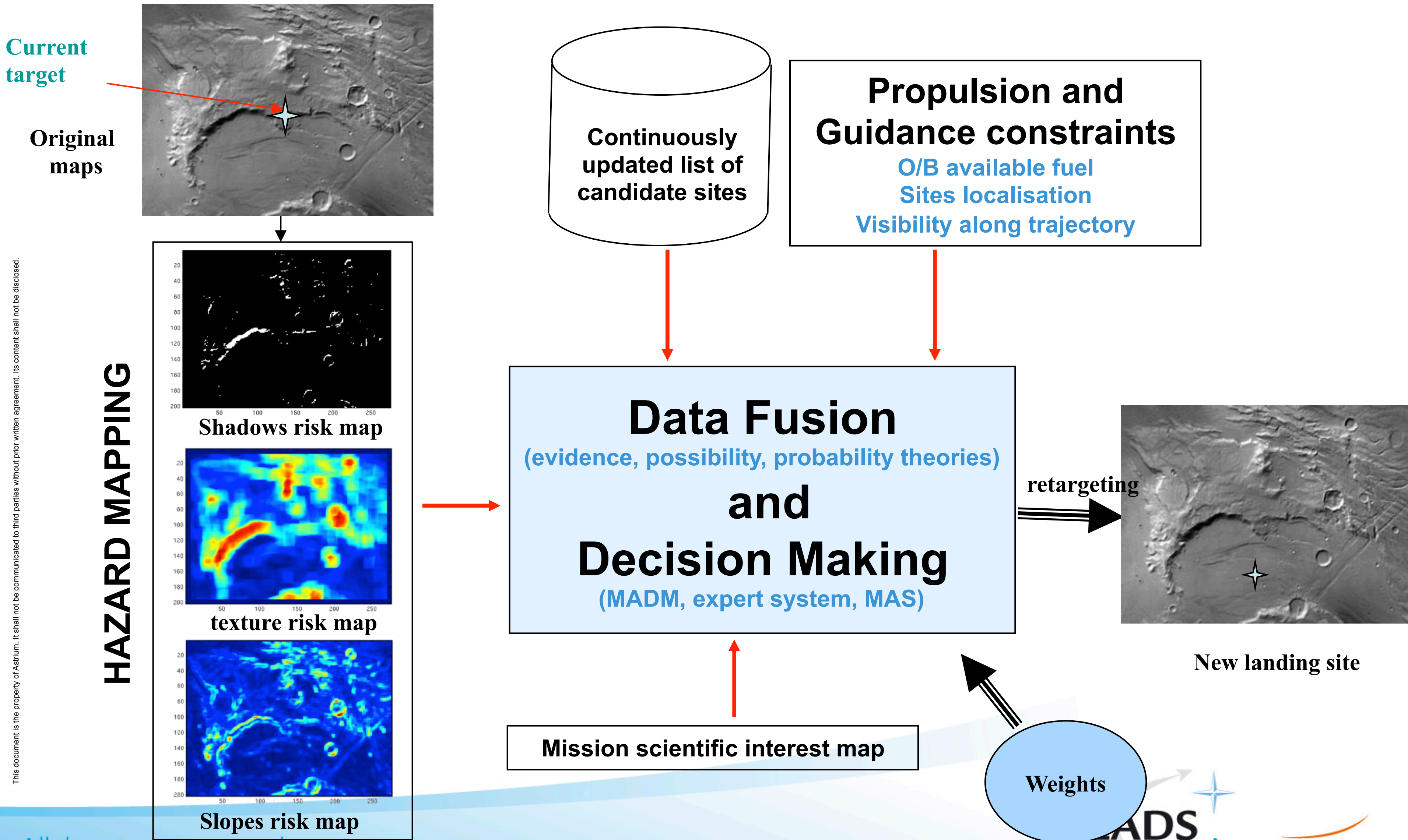
# Trade-off

- Vision based: flight proven sensor but real difficulties with slope estimation
- LiDAR based: slope estimation easy but sensor not mature yet
- High CPU and memory needs: hardware implementation may be necessary for RT feasibility

➔ In the long run LiDAR is the technology of choice

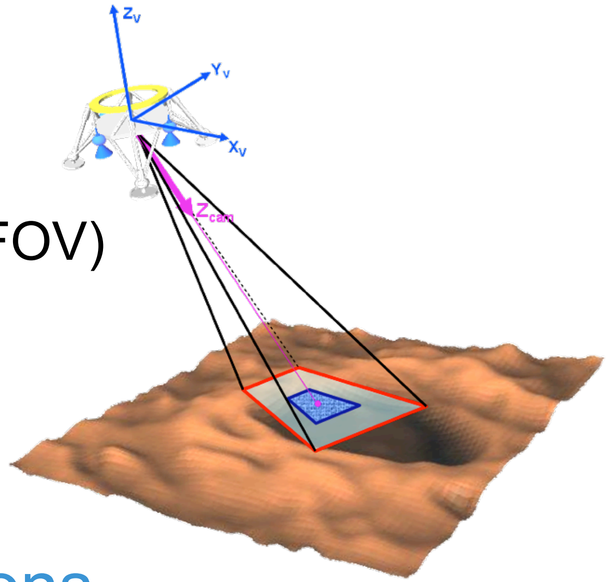
- Vision- and LiDAR-based HA to reach TRL5-6 by 2009 through dedicated ESA projects

# Site selection



# Trajectory planning & Guidance (1/2)

- Objectives: compute trajectory and acceleration required to reach the target while being compliant with:
  - soft-landing requirements (altitude/velocity)
  - fuel budget
  - visibility constraints (keep target inside sensor FOV)
  - enabling retargetings
  - limited on-board computational burden




- and robust to off-nominal flight conditions





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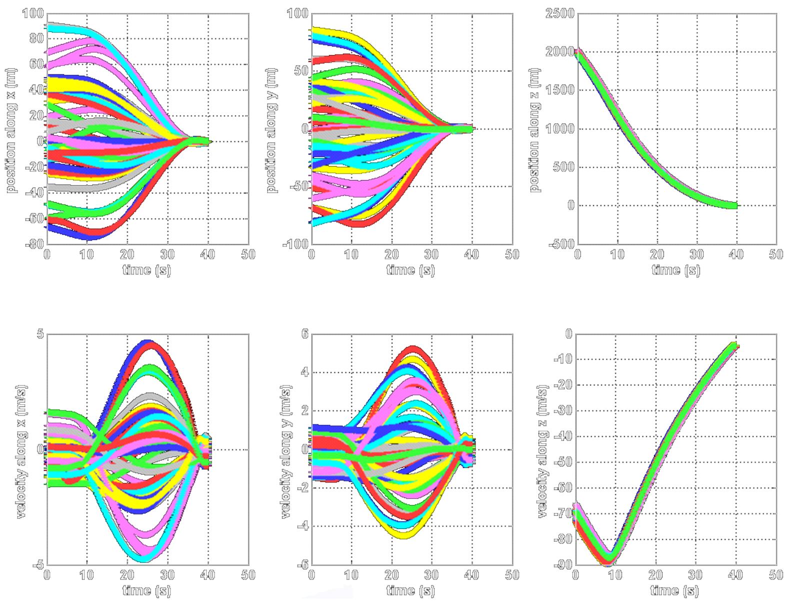
# Trajectory planning & Guidance (2/2)

- Gravity Turn: simplest solution (see Viking lander)
  - Poor accuracy and no hazard avoidance capability
- Simple dynamic equations : the two-points boundary problem can be solved in an explicit form
  - ➤ simple explicit methods:
    - Apollo E-guidance
    - Bilinear Tangent Law
    - Chandler scheme, etc.
  - ➤ More sophisticated methods

    in-house developed :
    - Optimal Command (or Predictor-Corrector)
    - G-guidance
    - Collocation methods
    - Neural Networks

➔ High landing accuracy, lower fuel consumption and robust to off-nominal I.C.




**Monte Carlo results**

# Conclusion

- EDLS is a key element for the planetary exploration
- Hard landing was flight-proven by NASA thanks to MPF and MER

- Next step is to land in remote areas
  - Soft-Landing is the next step for EDLS
  - Associated function is hazard avoidance

⇨ Thanks to its experience and technologies Europe is able to develop this capability for EDLS and gain a valuable place in the exploration route